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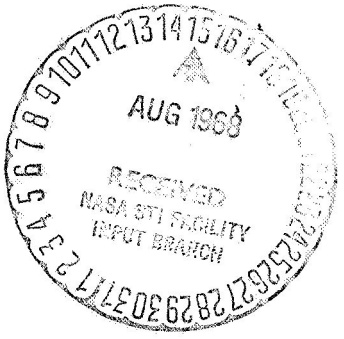

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SELECTIVE EXCITATION OF ARGON IONS BY METASTABLE HELIUM ATOMS

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ABSTRACT: The higher intensity of certain argon spark lines is associated with inelastic collisions of metastable helium atoms with argon ions.

Up to now only certain types of inelastic collisions between atoms and ions have been adequately investigated. A classification of inelastic collisions [1], in which the internal energy of both systems changes and excitation of some system occurs, is given in Table 1. The interacting systems are designated by the letters A and B; electronic excitation—by the prime, ionization—by the plus sign. The change in the kinetic energy of the interacting systems, equal to the difference between the energies of the initial and final states, is designated by ΔE. /121*

The condition of quantum-mechanical resonance and the Wigner rule lead to the selective excitation of ionic or atomic levels. The excitation probability is highest for states for which the energy defect is comparable to the average kinetic energy of the atoms or ions, i.e., $\Delta E \sim KT$. /122

Some data are presented in this paper concerning inelastic collisions of excited atoms with foreign gas ions with transfer of the excitation to the ions

$$A' + B^+ = A^{+\prime} \pm \Delta E.$$

Argon and helium are a convenient pair of gases for such an investigation. In the argon ions there are levels corresponding to doublet and quartet states whose energies differ slightly from the energy of metastable 2^3S helium atoms. The Wigner rule allows the transfer of the excitation from the metastable helium atoms to both the doublet and quartet states of the argon ions. By analogy with atomic collisions one should expect the selective excitation of those argon ion levels that are located near the metastable helium level.

Argon, compared with helium, is an easily excited gas. A discharge in a hollow cathode was used for studying the helium-argon mixture. The Kovar discharge tube had a diameter of 1.3 cm and a length of 15 cm. The so-called blue argon spectrum, consisting primarily of the spark lines of argon, was excited in pure argon in this tube. Shown in Fig. 1 is a trace of the argon spectrum in the blue-violet portion of the spectrum for a discharge current of 700 mA and an argon pressure of 0.4 mm Hg. The trace was made on an IKS-12 spectrograph. The entrance slit width is 0.035 mm. Since reabsorption of the radiation of the

*Numbers in the margin indicate pagination in the foreign text.

TABLE 1.

Attribute	Symbolic notation	Examples of physical phenomena in which this collision occurs
Transfer of electronic excitation	$A^1+B \rightleftarrows A+B^1 \pm \Delta E$	Sensitized fluorescence Excitation of spark lines by foreign gases
Transfer of charge	$A^1+B \rightleftarrows A+B^{+1} \pm \Delta E$ $A^+ + B \rightleftarrows A+B^{+1} \pm \Delta E$	Ditto

spark lines of argon is practically nonexistent, from the line intensity one could estimate the population of the corresponding argon ion levels. The spark lines of argon with levels far removed from the helium 2^3S level, which should not be excited by the metastable helium atoms, can be chosen as comparison lines. For example, the lines

$$\lambda = 4609\ \text{Å}\ (E = 21.05\ \text{eV}),\ \lambda = 4103\ \text{Å}\ (E = 22.5\ \text{eV}),$$

$$E\ (2^3 S_{\text{He}}) = 19.81\ \text{eV}\ (159\,844\ \text{cm}^{-1})\ [2].$$

Selection of argon atomic lines is unsuitable because the argon ion density changes with the addition of helium; and the intensity of the spark lines is, first of all, proportional to the ion density. Shown in Fig. 2 is a trace of the discharge spectrum in a helium-argon mixture for an argon pressure 0.4 mm Hg and a helium pressure of 6 mm Hg and a discharge current of 700 mA. The trace was made at a 2:1 reduction with respect to the trace of the discharge in pure argon (see Fig. 1). A comparison of the intensity of the argon spark lines in the pure argon and in the helium-argon discharges illustrates the selective character of the excitation of the individual argon ion levels by the metastable helium atoms. As expected, the maximum excitation transfer cross section from helium to argon ions is observed for levels located near the 2^3S_{He} level.

The ratios of the intensities of some argon ion lines to the intensity of the 4103 Å line in the argon discharge (K_1) and in the argon-helium mixture (K_2) are listed in Table 2.

The values of the energy defect ΔE_1 and ΔE_2 are given for the two initial argon ion states $3\,S^2\,3\,p^5\,2P^0\ (1\,1/2)$ and $3\,S^2\,3\,p^5\,2\,P^0\ (1\,1/2)$, respectively.

The table provides a good illustration of the resonant character of the excitation transfer from helium to argon ions. The ratio of the coefficients k_2/k_1 clearly shows the excitation efficiency of the argon ions by the metastable helium atoms, compared with the electronic excitation of the argon ions for the given discharge conditions.

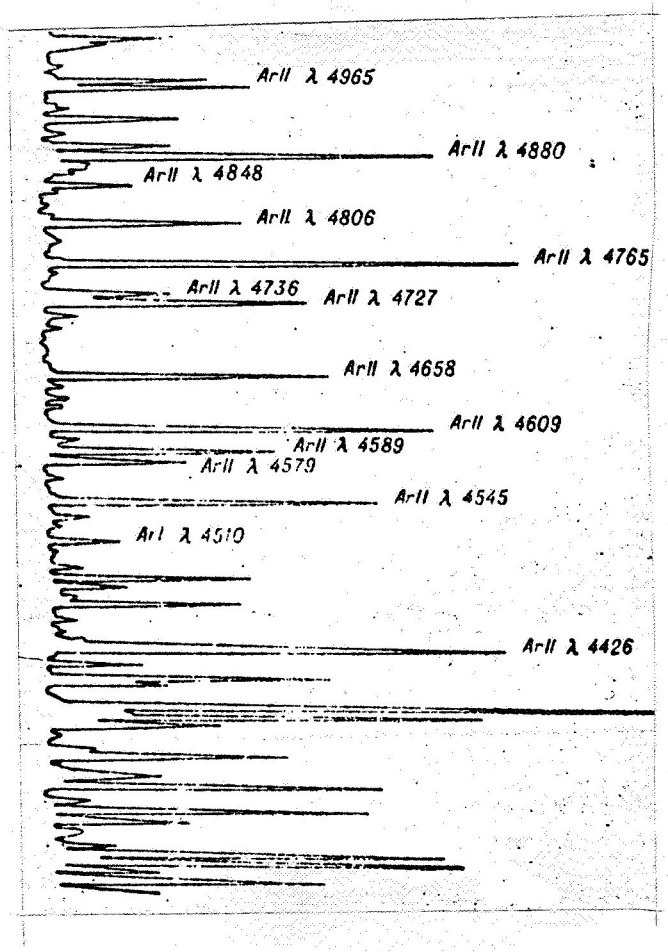

Figure 1.

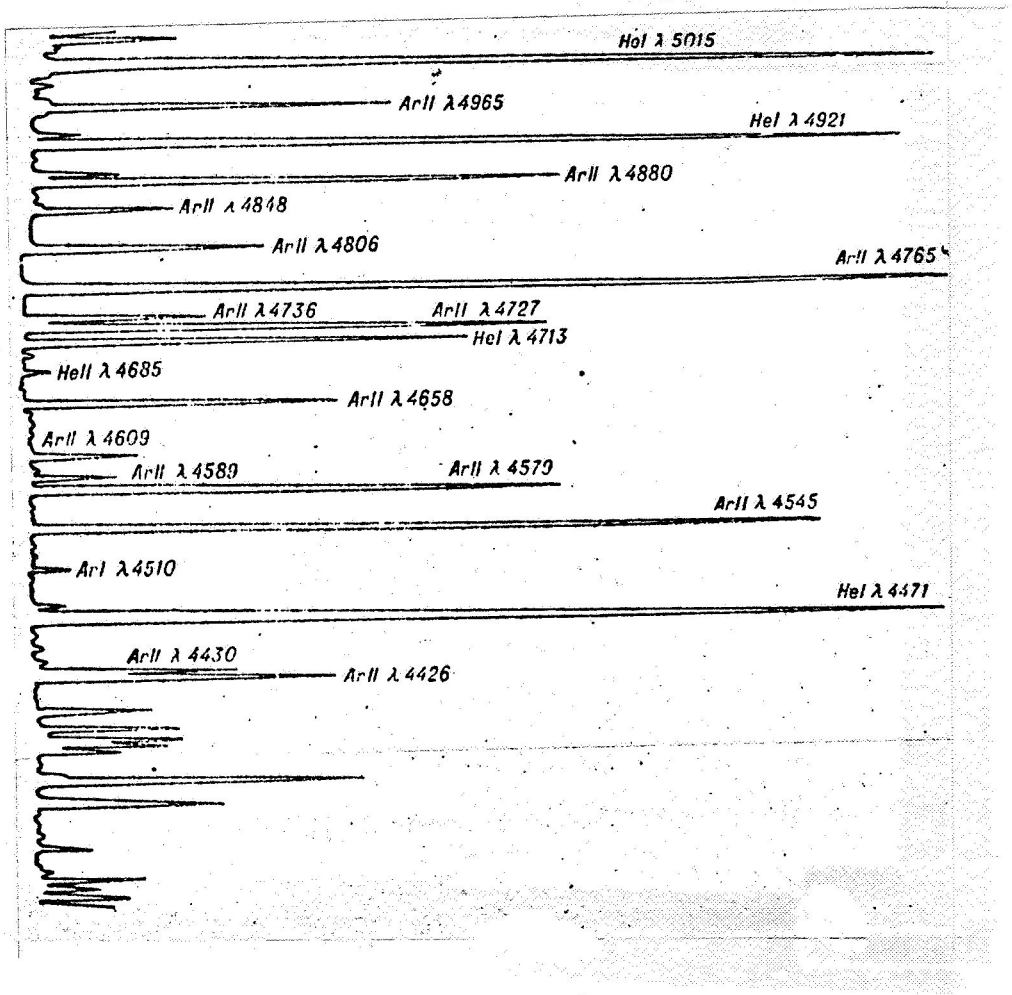

Figure 2.

TABLE 2

Line, Å	Upper state	ΔE_1, cm^{-1}	ΔE_2, cm^{-1}	Term value, cm^{-1}	$K_1 = \frac{I_\lambda}{I_{\lambda 4103}}$	$K_2 = \frac{I_\lambda}{I_{\lambda(Ar+He)}}$	$\frac{K_2}{K_1}$
4880	$4p^2\,D^0(2^1/_2)$	+1140	+2571	158696	2.9	14	4.8
4848	$4p^4\,P^0(1^1/_2)$	+4527	+5858	155317	0.71	4	5.6
4727	$4p^2\,D^0(1^1/_2)$	+485	+1916	159359	2.1	14.5	6.9
4579	$4p^2\,S^0(^1/_2)$	−1211	+220	161055	1.2	14.2	12
4545	$4p^2\,P^0(1^1/_2)$	−361	+1070	160205	2.7	25	9.4
4609	$5s^2\,D\,(2^1/_2)$	−10523	−9092	170367	3.7	3.5	0.95

The dependence of the intensities of some lines, in relative units, on the helium pressure is shown in Fig. 3 for a discharge current I_d = 600 mA at an argon pressure of 0.4 mm Hg.

The addition of helium leads to some decrease in the intensities of all lines. This is evidently associated with a decrease in the average energy of the electrons in the hollow cathode because of an increase in the total gas pressure since the average electron velocity in the hollow cathode is determined primarily by the electron mean free path length. In this region the line intensities are determined by electronic excitation of the argon ions. With an increase in helium pressure the density of metastable helium atoms increases and, consequently, so do the line intensities of the argon ions which are excited because of inelastic collisions of argon ions with metastable helium atoms.

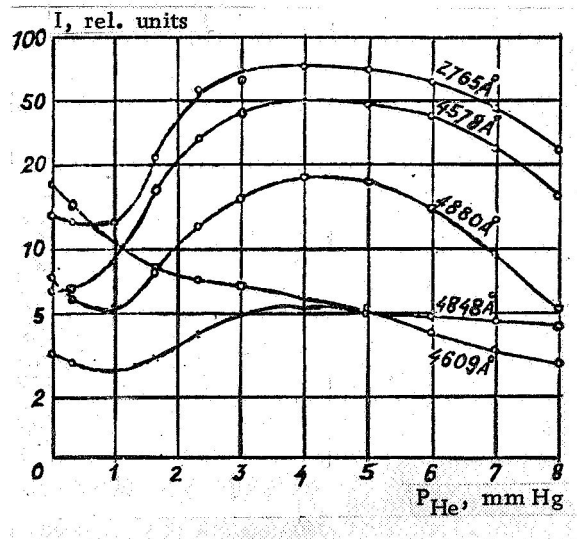

Figure 3.

With a further increase in helium pressure the intensities of these lines begin to fall. The decrease is caused, on the one hand, by the reverse process of excitation transfer from the argon ions to the helium atoms and, on the other hand, by a decrease in the argon density. The intensities of the Ar I 4510 Å, Ar II 4103 Å and Ar II 4609 Å lines, the excitation of which is determined only by electron collisions, decrease with an increase in helium pressure.

A measurement of the relative density of metastable helium atoms as a function of helium pressure at a constant discharge current is of interest. To this end the absorption of the 10830 Å helium line by the metastable atoms was measured; from this one could estimate the density of the latter. A discharge tube, similar to the one used in the experiments, was used as the light source; the

light source was modulated at a frequency of 1300 Hz. The signal from a PMT output was fed to a phase detector. The use of light source modulation allowed one to ignore the intensity variation of the 10830 Åline in the discharge tube. The relative density of metastable helium atoms had a maximum value at the helium pressure at which the maximum was observed in the intensities of the argon spark lines.

Thus, the increase in the intensity of certain spark lines of argon is associated with inelastic collisions of metastable helium atoms with argonions. The transfer probability is greater, the smaller the energy defect ΔE.

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